Commercialization of a New Stove and Fuel System for Household Energy in Ethiopia Using Ethanol from Sugar Cane Residues and Methanol from Natural Gas

Project Overview

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Introduction

This project seeks to revolutionize the household energy economy of Ethiopia and Africa by leading the way to alcohol fuels derived from currently wasted or under used resources, both biomass and hydrocarbon resources, for daily household use—for cooking, refrigeration, heating, lighting and electrical generation. A unique set of circumstances exists within Ethiopia that will allow Ethiopia to lead the way in this endeavor. It is anticipated that a new business will be established in Ethiopia after studies are completed and that this business will respond to a local and national market and also to an export market to other African countries.

The project commences with a pilot study that will deploy approximately 850 stoves for testing by end users and by various institutions and agencies, public and private, providing services to people in need. Approximately 500 stoves will be deployed in private residences in Addis Ababa and approximately 300 stoves will be distributed to institutions/agencies for use either within Addis Ababa or elsewhere in the country. Fifty stoves will be used for training and display. These stoves will be fueled by ethanol to be made available by Finchaa Sugar Factory for this purpose.

The pilot study formally commenced on August 7, 2004 with the training of 20 field surveyors whose mission was then to work with the municipal government of Addis Ababa to select participants for the survey in the city. During the training session, the Municipality kindly made its Subcity Administrators available to assist in the training of the surveyors. As of this week, a baseline study of the 500 selected homes has been completed and stoves are now ready to be introduced into the study homes. This will be an exciting moment for the project—when stoves first go into homes. This should occur during the first and second weeks of November. The pilot study will run into 2005 and will be concluded by June 30, 2005.

Coming together for this project are Dometic AB, a Swedish company, the world's leading alcohol stove and appliance manufacturer (until recently a part of Electrolux AB), Finchaa Sugar Factory, the ethanol manufacturer, Iacona Engineering, a furniture, appliance and metal goods manufacturer located in Addis Ababa and possessing the capability of making the Dometic stove and other appliances in Ethiopia, the Government of Sweden, the Government of Ethiopia, its Rural Energy Development and Promotion Center, the UNDP Global Compact and Winrock International, an experienced NGO active in many parts of the world in clean energy development projects. The Shell Foundation Sustainable Energy Programme is a sponsor of this project and Shell Ethiopia is an important facilitator.

The project is known by the title "Project Gaia" after the Greek goddess of the earth.

We present here an overview of the safety attributes of the lead appliance to be introduced—the CleanCook stove—and also the safety attributes of alcohol fuels. Given proper appliances in which to use them, alcohol fuels are ideal for household use.

Detail is provided regarding the performance of the CleanCook stove, its efficiency, operating characteristics and attributes with regard to safety, durability and ease of operation. Likewise, discussion is devoted to the characteristics of alcohol fuels, their safety, cleanliness, convenience, economy and environmental benefits. These fuels—ethanol and methanol—can be produced from undervalued or wasted biomass resources and from natural gas. Ethiopia possesses a substantial natural gas resource, which remains unexploited because of the difficulty and costliness of bringing it to market despite Ethiopia's urgent need for energy fuels. This project anticipates the possibility for monetizing Ethiopian natural gas in a domestic alcohol appliance fuel market with technology and infrastructure that are affordable to Ethiopians and can be paid for by the revenues generated from the sale of alcohol in this market.

This project is predicated on the belief that the household fuel market is the *highest and best use market* for Ethiopian ethanol and an excellent low-cost, easy-to-enter market for Ethiopian natural gas, one that does not require a large capital investment to be established. As a result, this market could help to "jump start" natural gas extraction, processing and use in Ethiopia. The role of ethanol in the pursuit of this opportunity should not be underestimated, as it is the availability of ethanol that will first establish the stove and alcohol appliance market. Without the availability of ethanol, it is unlikely that such a market will be begun. Once the market is established, the methanol will extend very significantly the opportunity that will have been created by the availability of ethanol and will make this an important market—and alcohol fuels an important energy resource—for Ethiopia.

Project Summary

Project Gaia teams Dometic AB, a manufacturing and sales company of Swedish origin, with Iacona Engineering, Ltd., an Ethiopian manufacturing and sales company, in an endeavor to introduce high quality but affordable alcohol appliances to Ethiopia and other African countries. The lead appliance is a safe, efficient alcohol burning stove, the "CleanCook" stove, based on a stove in use in the Europe, North America and other countries for over 25 years but redesigned to permit manufacture at one-third the cost of the original stove.

The opportunity in Ethiopia is threefold. First, Ethiopia possesses a thriving sugar industry. One of four plants, the Finchaa Sugar Factory, now produces annually 8 MM liters of ethanol from raw molasses, an underused manufacturing residue, in a state-of-the-art distillery. If highly purified ethanol is not the requirement of production, the Finchaa Sugar Factory may be able to extend its production to 12 MM liters annually. The other sugar factories, Metehara and Wonji Showa, have sufficient raw material feedstock to produce, combined, an estimated 20 MM liters of ethanol per year, were they to build distilleries at their plants. We are told that Metehara is considering an ethanol plant. Ethanol can be produced quite cheaply (about US 7¢/gallon excluding capital and raw material costs) and could be available for sale cheaply into a household fuel market, were one to be developed by making appliances that use ethanol available to the general public.

In addition to its agriculturally based ethanol resource, Ethiopia also possesses very substantial natural gas reserves in its Ogaden Basin. Confirmed supplies are in excess of 100 billion cubic meters with substantial additional supplies estimated. Through a highly selective, simple and efficient gas synthesis process, natural gas can be converted to methanol. This can be achieved economically with large or small plants, including skid-mounted modular plants that can be conveyed by truck to remote areas. Methanol production requires far less costly infrastructure than all other options for bringing the natural gas to market, including Gas-to-Liquids, Liquefied Natural Gas (LNG) or direct power generation from natural gas. Methanol, a simpler alcohol than ethanol, can be blended with ethanol in any proportion to make a superb alcohol fuel. Methanol and ethanol are blended in Europe and North America and other

countries for this purpose. Thus, the availability of indigenously produced methanol could greatly extend the supply of ethanol.
A technical partner on the Project Gaia team is HydroChem of Linde AG. HydroChem is the largest supplier worldwide of small gas synthesis plants to industry.

Second, Dometic AB, which possesses the highest-performing and safest alcohol stove made today, has developed a relationship with a quality metal goods manufacturer in Addis Ababa, Iacona Engineering, that has the capability of manufacturing the Dometic stove and other appliances that could be licensed for manufacture in Ethiopia. Iacona also possesses the capability of marketing these stoves, as it has wholesale and retail operations as part of its business. Iacona Engineering has 30 years of operating experience and produces a very varied product line of high-quality goods.

Third, there is a great need in Ethiopia for better energy choices in the household. All petroleum fuels are imported by the Ethiopian government at great cost to the Ethiopian people. There is a heavy reliance on biomass fuels, particularly fuel wood, which is burned directly or used to make charcoal in a dirty and wasteful process. The harvesting of native and plantation trees in Ethiopia has not been sustainable for many years; the impact of fuel wood harvesting is now critical. Any energy choices created that can reduce the dependence of the Ethiopian people on fuel wood will obviously be beneficial, although Ethiopia is so “energy hungry” that a large and comprehensive solution, one driven by the federal government itself, is urgently needed.

Project Gaia, after very thorough preparation, began its activities in Addis Ababa in August 2004 by putting in place a field team whose purpose will be to introduce some 800 stoves on a trial basis into various settings. Five hundred homes in Addis Ababa have been selected to receive a stove and ethanol fuel for consumer testing over a three-month period. The first of these stoves will be introduced during the month of November. Approximately 300 stoves will be placed in institutional settings for testing in special environments—in hospitals, clinics, schools, orphanages, public housing blocks, resettlement communities and emergency shelters—in and outside of Addis Ababa. Thus far, arrangements have been made to place 150 stoves through the UNHCR into two refugee camps, one at Sheraro near Axum and one at Kebri Beyah east of Jijiga. Additionally, 50 stoves will go into an IDP camp at Dhenan with the facilitation of the Ogaden Welfare and Development Association (OWDA). And 20 stoves will go to the Mother Teresa Mission of Charities for use in their 14 orphanages located throughout Ethiopia.

The pilot study will assess issues related to existing stove final design, new stove design, fuel handling, packaging and delivery, consumer safety, stove and fuel distribution logistics, stove and fuel affordability, cost of infrastructure development, the need for and extent of government buy-in and supportive public policy, design of a commercial project, and how to finance the commercial project so that it will address the need in the marketplace and reach the largest number of consumers. Both a consumer retail market and a market for specialized institutional buyers are to be explored. The project has sought the advice, counsel and participation of the Municipality of Addis Ababa, the Ethiopian Rural

Energy Development and Promotion Center, the UNDP, the UNHCR and relevant NGOs in carrying out the pilot study.

The CleanCook Stove

The CleanCook stove is modeled after the leading alcohol stove in use in Europe and North America for over 25 years. It is a high-performance stove, one of the most efficient stoves on the market today. It is constructed entirely of stainless steel and is durable and long lasting, with only one moving part. It has an estimated minimum 10-year life. In fact, the stove has a much longer probable useful life—15 years or more. When burned with methanol or a methanol-ethanol fuel blend, it burns very cleanly, without any odor, soot or smoke, and pots stay clean and bright. When burned with ethanol alone, a small amount of soot will form and some odor will be detected when pots are cold; however, this odor quickly dissipates as the pot heats. Ethanol has a slightly more complex chemistry than methanol, but ethanol also has a higher heating value than methanol. A discussion of the properties of these two fuels, their chemistry, and their advantages with regard to safety and air quality when combusted follows.

The model to be used in the pilot study has two burners, each of which provides 1.5 to 2 kW of heat output. This is similar to the heat output of a typical LP gas burner. Like the typical LP gas stove, this stove has an efficiency rating of 50% to 55%, which is the effective peak efficiency (defined as efficiency of heat transfer) for any stove on the market today. A liter of water will boil on the CleanCook burner in about 7 ½ minutes. This compares favorably to a typical LP gas burner and exceeds the performance of a standard electric burner.

Each CleanCook burner has its own fuel canister that holds 1.2 liters of fuel, sufficient for 4 ½ hours of cooking. Thus, a two-burner stove provides approximately 9 hours of cooking before the fuel canisters have to be refilled. The canisters are easily refilled from a one- or two-liter plastic bottle provided for that purpose.

The alcohol fuel burns with a clean blue flame. Alcohol fuel has excellent safety properties. In the open, alcohol burns with excess air and thus with a lazy, cool flame. It can easily be put out by water, because water and alcohol mix in any proportion. It will not flare up or burn aggressively outside of the chimney of the CleanCook stove. In contrast, kerosene, when spilled from a kerosene stove—an all too common occurrence—burns with a hot flame that is spread by water. Spilled kerosene will flare up or flash. And kerosene in a typical wick stove can be explosive if the flame spreads to the fuel tank or if vapor pressure builds when the fuel tank becomes over heated. The CleanCook stove holds its fuel in an altogether different fashion that eliminates the risk of leakage, flare up or explosion.

The CleanCook stove does not hold its fuel in a closed container. The alcohol is retained in the canister in a unique, patented fashion. It is not held under pressure, but is held by capillary attraction to the surface of a carefully selected refractory mineral fiber that has been developed especially for this application. The fuel container is actually open at the top, possessing an evaporative surface from which the adsorbed alcohol evaporates into the heat of the flame in the stove chimney. Because of the low surface tension of alcohol, it adheres to the mineral fiber. But because of its excellent evaporative characteristics, it evaporates readily from the surface of the mineral mass into the heat of a flame. The addition of methanol to ethanol improves both the adsorption and the evaporative characteristics of the fuel, and also “oxygenates” the fuel with the result that no soot is produced and the trace amounts of aldehydes that are produced (which is the smell one detects with ethanol) are all but eliminated.

The burner chimney of the CleanCook stove mixes the alcohol fuel as it volatilizes from the canister with just the right amount of air to produce a hot and well-focused flame. This is an important attribute of the stove. Many alcohol burners burn with the typical “lazy” flame that one associates with a lit can of sterno and thus they do not perform satisfactorily—e.g. with low performance and efficiency. As a result, consumers will not buy them and use them. The alcohol Primus stove uses pressure to overcome alcohol’s “lazy flame” problem. One must pump the Primus stove to keep the fuel in the tank under pressure. The CleanCook stove overcomes this problem in an altogether different, much safer and more convenient way for the consumer. The need for a pressurized fuel feed is eliminated by the way in which the fuel canister has been designed to work with the burner chimney. When the CleanCook burner is lit and the chimney heats, the alcohol volatilizes rapidly from the open, evaporative surface of the fuel canister into the chimney, almost as if the alcohol were under pressure. In this regard, one could say that the CleanCook’s fuel feed process is “self pressurizing”. In a subsequent program, Project Gaia will introduce an alcohol mantle lantern, which is available as part of this project. It will be seen that the fuel feed mechanism of the lantern is indeed self-pressurizing, as the heat of the burning mantle is used to expand the alcohol in the supply tube from a liquid to a gas to force it through a nozzle. The unique properties of alcohol as a fuel create the opportunity for these types of innovations that have allowed us to create elegantly simple, high-performance, maintenance-free appliances. Such is the case for the CleanCook stove.

The flame in the CleanCook burner is adjustable, just as the flame of an LP gas burner or a Primus burner is adjustable. This allows the user to economize on fuel use. But the flame regulator of the CleanCook stove is simpler than that of a pressurized stove, because the opening and closing of a valve is not required, only the sliding of a plate across the evaporative surface of the fuel canister to reduce the amount of alcohol volatilizing into the flame. The flame regulator of the CleanCook stove is simple, “low tech” and rugged. It is the only moving part on the CleanCook stove and, if it were to break, it is easy to repair.

When working parts on appliances break, they are often not repaired by the consumer who nevertheless continues to use the appliance, often unsafely. An example is the typical “China” or Panda kerosene stove that loses the cap to its fuel tank, with the result that the consumer operates the stove with an open tank. The CleanCook stove eliminates all risk in this regard because of its simple and rugged design.

The alcohol fuel is retained in the CleanCook canister as a liquid, yet, as long as the canister is not overfilled (and the stove has been designed to make this almost impossible to do), it will not leak out of the canister. Unlike the Primus stove or a propane/butane canister, the canister of the CleanCook stove is not closed or pressurized; thus it cannot explode under any circumstance. The alcohol evaporates from the canister as a gas, and therefore behaves as a gas when burned. What we have here, as a result, is a fueling mechanism for the CleanCook burner that allows the alcohol fuel to be handled as any liquid fuel, but without the attendant risks of burning a liquid fuel, and burned as if it were a gas, but without the attendant risks of burning a gaseous fuel. Stated another way, we have the convenience of handling that comes with a liquid fuel, but the performance of a gaseous fuel, without the risks of either. As a result, because the CleanCook stove has found a way to harness alcohol and put it to work in a high performance burner, it has transformed alcohol from the "lazy" fuel into a very desirable and much sought after fuel, and from an already acknowledged environmentally friendly fuel into the cleanest, safest liquid fuel available to mankind.

Alcohol Fuels: Safety

It will have been noted from the above discussion that the CleanCook stove has been designed for safety. And indeed, the need for a very safe stove, to be employed in difficult situations—in boats—was the original motivation for the design and development of the Dometic Origo stove, of which the CleanCook stove is only the latest example. One of the reasons the Dometic Origo stoves are safe is because they employ alcohol, not kerosene or a flammable gas, as their fuel. Alcohol fuels can be evaluated for their safety by considering the following issues: toxicity, flammability and fire hazard, environmental impacts and products of combustion or impact on air quality when burned, particularly in the close environment of the home.

Toxicity: When used as a domestic fuel, both ethanol and methanol, whether blended or separate, should be denatured with a colorant, an odorizing agent and a bittering (tasting) agent to clearly identify them and render them unpalatable for ingestion. The Dometic Origo stoves are used in Europe and North America with fuel blends of ethanol and methanol that have been denatured for safety. A denaturing protocol has been developed by Dometic for use in denaturing ethanol and methanol. The denaturing agents help to color alcohol's clear blue flame to make it more visible in the daylight. This provides an additional safety measure.

Ethanol is widely used in the chemical, pharmaceutical and food industries, where long experience has shown that it is neither a serious hazard nor requires elaborate or unusual means to handle safely. As indicated above, it is a volatile compound, but it has a vapor pressure lower than most other liquid fuels. When straightforward ventilation practices are used, worker inhalation can be kept quite low. Moderate exposures to the vapors produce only temporary irritation of the eyes and respiratory tract. As airborne concentrations increase, the discomfort becomes intolerable well before a level that could cause suffocation or other dangerous effects. The threshold limit value (TLV) for prolonged exposure has been set at 1000 ppm by various U.S. and European regulatory agencies, while the corresponding TLVs for methanol, gasoline and kerosene are 200, 300 and ~20 ppm respectively. Five thousand to 10,000 ppm of ethanol in the atmosphere causes uncomfortable irritation, and eventual stupor or drowsiness. Intoxication, in the sense of drunkenness, from industrial inhalation is rare.[1]

Methanol is toxic, but it is less toxic than the petroleum fuels. In 1991, the U.S. Department of Energy concluded gasoline to be more hazardous to human health than neat (pure) methanol.[2] Methanol poses no known cumulative health hazard and is not classified as carcinogenic, mutagenic or teratogenic. The petroleum fuels are a complex blend of chemicals that include, for example, benzene, a chemical that is considered to be extremely toxic and carcinogenic. The U.S. EPA's Office of Air Quality Planning and Standards has determined that methanol offers little threat of chronic toxicity and it gives methanol a composite score of 7 on a scale of 1-100 (100 being the most toxic). EPA has likewise concluded that momentary dermal contact with methanol is not of significant concern.[3] Because methanol evaporates quickly and cleanly, it does not adhere to the skin or leave a residue on the skin.

Flammability & Fire Hazard: There are several ways to compare and contrast the fire hazard of alcohol fuels—ethanol and methanol—versus the fire hazard of hydrocarbon fuels—kerosene, gasoline and diesel. First, the lower flammability (or explosion) limit (LFL) can be considered for each fuel. Accidental fires often occur because flammable vapor increases from a low level to the minimum concentration at which ignition will occur. The higher the value for the LFL, the less likely a fire will result. Thus, a high value for LFL is considered to be safer than a low LFL value. Ethanol has a LFL value of 3.3% in air at room temperature and methanol a value of 6.0%. These values are significantly greater than for kerosene at 1.7% and gasoline at 1.4%. Depending upon the nature or composition of the kerosene, its LFL can sometimes be lower—as low as 0.7%. The LFL of diesel is 0.6%. (Values are from Material Safety Data Sheets and Lange's Handbook of Chemistry—See **Table 3** below).

Consistent with these values for the LFL of alcohols and hydrocarbon fuels is the minimum temperature at which the lighter hydrocarbon fuels will ignite (flash point). The flash point of methanol is 11º C and that of ethanol is 14º C, while the flash point of gasoline is – 45º C, and that of benzene, – 11º C. The flash point for kerosene and for grades of jet fuel is a more complex matter. The flash point may range between 21º and 82º C.[4] (The same situation exists for diesel fuel. Diesel fuel extended with light naphtha or light crude can reach flashpoints as low as 22º C, well below its normal prescribed range of 60º to 80º C.[5])

Like many countries, the Ethiopian government buys aviation grade kerosene for its domestic kerosene market. Aviation kerosene fuels are complex mixtures, containing hundreds of species of chemicals in varying amounts, depending on the crude oil and the refinement process, among other factors.

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[1] Kirk-Othmer Encyclopedia of Chemical Technology, Third Ed., 1980. Ethanol. Volume 9, p. 366.
[2] IdaTech "Tech Brief", January 2001. US DOE, October 1991. Technical Report No. 7.
[3] US EPA Office of Pollution Prevention and Toxics, 1994. Chemical Summary for Methanol.
[4] Shepherd, J.E., Nuyt, C.D. and Lee, J.J., May 2000. Flash Point and Chemical Composition of Aviation Kerosene (Jet A), Explosion Dynamics Laboratory Report FM99-4, CA Institute of Technology, ARCO Products Co. and Univ. Nevada, for NTSB.
[5] Queensland Government, Dept. of Training and Industrial Relations, May 1996. Health and Safety Alert, Alleged Illegal and Dangerous Practices in the Petroleum Industry, Queensland, Australia.

Typically Jet A will contain 18 to 20% aromatics including many lighter fractions. The vapor composition of kerosene fuel is different from that of the liquid and depends strongly on temperature and, to a lesser extent, on the amount of liquid fuel in the fuel tank. The explosion hazard of kerosene vapor will also depend in part on the ignition source.[6] Kerosene is no longer the relatively safe household fuel that it was in the past.

Gasoline, kerosene and diesel vapors are denser than ethanol or methanol vapor, and therefore are more likely to accumulate at the lower levels of a room near the floor where ignition sources are commonly encountered. A similar situation exists for propane, butane and LPG. They will seek the lowest space if they escape from their pressure cylinder. As they escape, they expand rapidly and cool. The very cold gas sinks.

The auto ignition temperature of kerosene is low, at 210º C, while those of ethanol and methanol are 363º and 460º respectively. Considering these higher auto ignition temperatures and the higher concentrations required to reach LFL for ethanol and methanol, as discussed above, the explosion hazard of the alcohols is substantially less than that of gasoline and kerosene.

Another fuel property to consider is latent heat of evaporation. More heat is required to evaporate ethanol than gasoline and more again to evaporate methanol than ethanol. When a liquid fuel evaporates, it is cooled. The Origo CleanCook fuel canister is designed to evaporate its fuel into the heat of a flame that burns above—not on—the evaporative surface of the fuel canister. As the fuel evaporates from the Origo fuel canister into the flame, the alcohol in the canister is cooled, because of the high latent heat of evaporation of the ethanol and methanol. Thus, the fuel in the canister and the canister itself stay cool.

Another way to evaluate relative fire hazard is to compare the severity of fires. Severity refers here to the amount of heat released during combustion, including radiated heat from the flames. In this respect gasoline and kerosene again compare unfavorably with the alcohol fuels. The hydrocarbon fuels burn with enormous release of heat. Much of this heat is radiated by the flames, making it difficult to approach the fire to extinguish it. Methanol and ethanol flames radiate less heat. As previously mentioned, when they burn outside of a controlled environment like the stove chimney, they burn in excess air, which produces the typical “lazy” flame of a can of sterno. For this reason, an alcohol flame can often simply be blown out. Since alcohol is 100% miscible in water, it is extinguished by water. Hydrocarbon fuels are not miscible in and their flames will only be spread by water.

Hydrocarbon fuels are also not miscible in ethanol, methanol or other alcohols. Mixtures of gasoline or kerosene with alcohol carry risks of phase separation, which can lead to nonoptimal performance and even danger when used in devices designed for either one or the other homogeneous fuel. The safest approach to using alcohols or hydrocarbon fuels in distributed, “low-tech” applications is to stay with a stable single-phase fuel, having a minimum of hazardous or incompatible additives.

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[6] Shepherd, Nuyt and Lee, May 2000.

The mixing of ethanol and methanol with hydrocarbon fuels for household use is strongly advised against. Not only does this project not mix fuels, it is premised on the fact that alcohol fuels do not need to be and should not be mixed to be used effectively. It will educate the participants in the pilot study and the consumer in general not to mix alcohols with hydrocarbon fuels. The CleanCook stove has been designed to discourage the use of any fuel other than alcohol.

If ethanol is mixed with kerosene and used in a kerosene stove, whether by accident or through ignorance, the results can be very dangerous. In contrast, if kerosene is used in a CleanCook stove, while the results would be very unsatisfactory, they would be only minimally dangerous. Loose kerosene, if ignited, will flare up as kerosene does, but the stove cannot be made to explode.

The fuel tank of a kerosene wick stove will pressurize and is not designed to handle pressure. Normally, the vapor pressure of kerosene is low and remains so during the normal operation of a wick stove. Ethanol in a wick stove would very likely raise the vapor pressure in the fuel tank and promote ignition and possibly an explosion. In contrast, filling the CleanCook stove with kerosene might result in a flare up (if one could even succeed in lighting the stove), but it would not result in an explosion. This is so because the CleanCook fuel canister is open and cannot be made to pressurize.

If kerosene is placed in the CleanCook fuel canister it can be burned or evaporated out to clean the canister. This would have to be done before the canister could be used again for normal, safe operation with ethanol or methanol fuel.

A Note about the Hygroscopicity of Alcohol: Ethanol's attraction of water creates a problem when blending with gasoline for motor fuel use, namely, the separation of an alcohol–gasoline blend into an aqueous alcohol phase and a gasoline–hydrocarbon phase. This not only means that the alcohol to be blended must be anhydrous, but also that great care must be taken to assure that storage, transport and service-station tankage is free of water. A small amount of water is enough to cause phase separation, even in blends containing as much as 25% alcohols.

Even the best precautions at the refinery, in transit and at service stations cannot prevent the possibility of water-phase separation in automobile fuel tanks. Such separation can cause corrosion, rough engine operation, starting problems and fuel-line plugging.

In contrast, the hygroscopicity of alcohol poses no problems for its use as a stove fuel. Indeed, some water in the alcohol is beneficial. Alcohol containing as much as 10% water can be burned without problem in the CleanCook stove. The ethanol-water azeotrophe (or the mixture which nature seeks), is 95% alcohol, which is quite desirable as a stove fuel but cannot be used for gasoline blending. Thus, the hygroscopicity of alcohol, while it presents a problem for the use of alcohol in internal combustion engines, does not present a problem for use as a stove fuel.

Environmental Hazards: Ethanol and methanol mix readily with water and quickly degrade in the environment. Hydrocarbon fuels do not mix with water and do not degrade rapidly in the environment.

For these reasons, the U.S. Department of Energy determined that the environmental hazards created by gasoline, kerosene and diesel fuel spills were greater than those created by ethanol and methanol releases.[7] Moreover, studies have determined that ethanol and methanol are essentially non-toxic to a variety of aquatic of plants and animals tested,[8] while gasoline and petroleum fuels in general are very toxic to aquatic life.[9]

Products of Combustion/Air Quality: Health benefits accruing as a result of the cleanliness of ethanol and methanol when burned as compared to the smoke, particulate matter and complex mix of organic compounds produced by the burning of biomass fuels and kerosene are very significant. The long list of products of combustion of wood and kerosene include smoke and soot (particulate matter), benzene, butadiene, formaldehyde, carbon monoxide, polycyclic aromatic hydrocarbons, dioxins, furans and so on. Extensive study has been devoted to the health impacts of smoke and fumes from biomass and kerosene fires. Sufficient here is simply to document the cleanliness of alcohol when it burns.

Below are the emissions data from a laboratory report produced for Dometic and its South African agent by Chemtaur Technologies Laboratory (Johannesburg) in 2001. This study was completed in conjunction with a small pilot study that was conducted in the town of eMbalenhle near Johannesburg by NOVA Institute, a South African non-governmental organization specializing in household energy and community health, using fuel methanol provided by SASOL. This study shows that the primary products of combustion of ethanol and methanol are CO_2 and water vapor, with only parts per million of formaldehyde or acetaldehyde (<1), carbon monoxide (<20) and uncombusted ethanol and methanol vapors (<5), all well under the published exposure standards. No measurable NOx (<1) was produced.

Analyte	Unit	Test 1	Test 2	Test 3	Test 4
Time to burn ~500mL fuel	minutes	129	127	130	125
Water left from 2500mL	mL	509	899	412	738
Carbon monoxide, CO	ppm	19	17	20	20
Carbon dioxide, CO_2	ppm	2050	2100	2450	2400
Nitrous fumes, NO_x	ppm	<1	<1	<1	<1
Formaldehyde, HCHO	ppm/hrs	<1	<1	<1	<1
Ethanol, C_2H_6O	mg/m^3	2.97	<0.01	3.77	<0.01
Methanol, CH_4O	mg/m^3	<0.01	6.54	<0.01	11.15

Table 1: Test Methods used were as follows: The tests were performed by burning the stove in a tightly closed room of a volume approximated at $35m^3$. Test 1 was performed with ethanol with one burner burning. Test 2 was methanol with one burner burning. Tests 3 and 4 were with two burners burning, ethanol and methanol respectively. The nitrous fumes, carbon monoxide and carbon dioxide were determined with Dräger color-tubes. The methanol and ethanol concentrations were analyzed by

[7] IdaTech "Tech Brief", January 2001. US DOE, October 1991. Assessment of Costs and Benefits of Flexible and Alternative Fuel Use in the US Transportation Sector. Technical Report No. 7: Environmental, Health and Safety Concerns.
[8] US Environmental Protection Agency, Office of Pollution Prevention and Toxics, 1994. Report No. EPA 749-F-94-013a.
[9] Machiele, Paul A., 1989. A Perspective on the Flammability, Toxicity and Environmental Safety Distinctions Between Methanol and Conventional Fuels. Prepared for the AIChE. USEPA. Ann Arbor, Michigan.

GC/MS and the formaldehyde was determined using a KLM color comparator. The mg/m^3 measure is approximately equivalent to a ppm measure.

The Pilot Study

The pilot study is being conducted under the direct supervision of Iacona Engineering PLC assisted by Dometic AB and the Stokes Consulting Group, the Ethiopian Rural Energy Development and Promotion Center and the Municipality of Addis Ababa. A technical team has been established to serve as a steering committee for the pilot study, capable of addressing any safety, logistical or technical issues that many arise. This team includes Finchaa Sugar Factory personnel, a member of the Ethiopian Society of Chemical Engineers, a representative of the Shell Foundation, and other members.

Management staff at Iacona Engineering oversee the study on a daily basis. They have in place a field survey team composed of 16 surveyors and 4 quality control staff who are supported by an office staff of two. The effort is also currently assisted by two specialists provided by the Stokes Consulting Group and Dometic AB.

The municipal government kindly agreed to work closely with Project Gaia and its field team to select homes for the survey. Diversity among homes with regard to income, socio-economic indicators, cooking practices, and so forth was sought with the guidance of the Subcity Administrators and heads of Kebele. Geographic proximity of the homes (in groups) was also sought in each of the sample Kebele in order to promote efficiency in the survey work. A thorough baseline study of the homes selected measuring existing conditions (existing cooking habits, cost of stove(s), cost of fuel, etc.) has been completed and each home will receive personalized training on the use of the stove prior to the stoves being introduced into the homes.

Upper level university students from Addis Ababa University were recruited to perform most of the field work. A dedicated quality control staff was put in place to monitor the work of the field surveyors. Each field survey team has a team leader. All field survey staff received training before going into the field. All field staff have been required to thoroughly record their activities in the field. Householders participating in the field study have also been asked to keep a record of the visits received by survey staff, so that survey staff performance can be monitored.

Throughout the study, the assignment of field staff to homes will remain consistent. It is intended that the same staff will visit the same homes each week. In this manner, each surveyor will become known to the households to which he or she is assigned.

All members of the survey team wear a distinctive cap and shirt when in the field, clearly identifying them as Project Gaia survey staff.

As mentioned previously, participating homes are being given group and individual training in the proper use of the CleanCook stove and ethanol fuel before the stove is placed in the home. (Only ethanol fuel is being used during this pilot study.) During the first week that the stove is in the home, field staff will perform two house visits to monitor the family's use of the stove. Thereafter, one house visit per week will be made, unless more frequent visits are indicated for a particular home. This will continue for at least one month. Thereafter, the visits to each home will become less frequent, with one visit every two weeks as the standard.

Ethanol will be provided to each study home free of charge each week for the first four weeks. At the end of the first month, some cost will be placed on the ethanol. At the end of two months, the ethanol will be sold to the study homes at a probable retail price, not established at this time but expected to approximate or be slightly under the cost of kerosene. At the end of six months, study participants will be given the opportunity to purchase their stove at a nominal price as a way of thanking them for participating in the study. Stoves not purchased will be returned to the project.

Observers will be invited to accompany surveyors into the study homes provided that these homes agree. Observation of the field study process will be encouraged, within the limits set by the householders themselves.

Which Stoves Will the CleanCook Stove Replace?

Our pilot study will help to answer this. The brief analysis provided in tabular form below is designed to show what is possible. The analytical process used must be tailored to different markets, for example an urban or a rural market. The table below is based upon the conditions that prevail in Addis Ababa.

This table evaluates the probable impact of the CleanCook stove and alcohol fuel, given their desirability, against other fuels and their stoves, assuming: (1) that stove cost is a neutral factor, (2) that the supply or availability of ethanol/methanol is not an issue and, (3) that ethanol/methanol can be priced competitively with kerosene. This table shows likely change motivators for each of the fuels currently in use in Addis Ababa. These motivators will promote change away from existing fuels if a satisfactory alternative is provided. The table shows where change motivators accumulate and thus where change is most likely.

Market Sector	Electric	LPG	Kerosene	Charcoal	Wood	Dung	Leaves & Twigs
Upper Income	A	A		A			
Middle Income	AE		QSAE	CAE	QCAE	QCA	QC
Lower Income			QSAE	CAE	QCAE	QCA	QC

Table 2: Potential Impact of the CleanCook Stove on Fuel Choices by Market Sector, with Stove Pricing as a Neutral Factor

The change motivators considered are as follows:

CHANGE MOTIVATORS:

Q = Quality	A = Availability
C = Convenience	E = Economy
S = Safety	

The lightly shaded areas show where there is possibility for impact by the CleanCook stove on cooking choices and the more darkly shaded areas show where there will be a higher likely impact on cooking choices.

<u>Discussion</u>:

- When electricity is out, availability is an issue for the upper-income market sector.
- For the middle-income market sector, the cost of cooking with electricity has become an issue.
- For the middle-income sector, kerosene carries issues of quality, safety, availability and economy. All change motivators are here except convenience of use, since use and handling of ethanol fuel will more or less resemble that of kerosene, as both are liquid fuels.
- For the middle or lower-income sectors, fuel wood carries issues of quality, convenience, availability and economy, especially in the city. Safety may not be a compelling change motivator, since the handling of wood fires is well understood. (This is not to say that safety—the hazard of burns and accidental fires—is not an issue with solid biomass fuel fires. But with this fuel safety may not be a strong change motivator.)
- Because charcoal is important in the tradition of Ethiopian cooking, issues of quality are offset. Thus, charcoal may be harder to displace than some other fuels. The economy (affordability) and availability of charcoal in the city are significant potential change motivators.
- Although there are well-understood issues of safety with solid fuels, these fuels are generally viewed as manageable, whereas safety issues with kerosene are viewed as more critical. Kerosene is felt to be unpredictable. Fires resulting from kerosene accidents are feared because they quickly become unmanageable and are especially difficult to extinguish.

This table suggests that the most likely fuels to be displaced by the CleanCook stove and ethanol/methanol fuel will be kerosene in the low- and middle-income sectors, and fuel wood in the low- and middle-income sectors. *This presents the opportunity for a significant health and environmental gain, and also an opportunity to reach lower-income people with improved fuels, the sector least served in this regard.*

The table also suggests that displacement of charcoal use may be a possibility. Thus, a key question to be answered by the pilot study will be whether or not the CleanCook stove can have an impact on charcoal use. Will families switch from the *Lakech* to the CleanCook stove? Likewise, there may be a possibility that cooking with electricity among middle-income users could be displaced by the CleanCook stove. Could the electric *mirte* give way to an ethanol-fueled stove designed to heat a *mirte* for *injera* cooking?

How Much Will The CleanCook Stove Cost?

There has been a concerted strategy thus far by Dometic AB to make the cost of the CleanCook stove affordable to the largest number of consumers. The manufacture of the stove was moved from Sweden (a high-labor-cost country) to Slovakia, a much lower labor-cost-country. The stove sold into the European and North American market was substantially redesigned to reduce the labor time required to manufacture the stove, so that it could be mass produced in large numbers with less labor and more automation. This required the design and purchase of new tooling and some new equipment in the Dometic factory, therefore this effort has required a not inconsiderable investment by Dometic.

The redesign of the stove has not compromised its quality or performance. All of the design elements related to stove, burner and fuel canister performance have been retained. The stove body was redesigned to make its manufacture more streamlined. At the same time, the stove body was made larger, stronger and more stable than the stove body of the prototype—the Origo 3000 stove.

Because of the cost of importing this stove into Ethiopia, and because of the relatively high schedule of taxes and tariffs that are charged on goods imported into Ethiopia, it has already become apparent that the stove will have to be manufactured in Ethiopia to make it truly affordable to the largest number of Ethiopians. The pilot study will answer the questions of when and how it will be manufactured here, and what stove designs will be used. The pilot study will also answer questions of how it should be priced, and what the best strategies are to price it to make it affordable to different market sectors.

For middle and low-middle income market sectors, micro financing programs can be developed. The pilot study will be used to generate information for designing one or more micro financing programs to increase the ability of consumers to buy the stove. But other strategies are to be investigated as well. Because of stove efficiency and the potential for the alcohol fuel to be cheaper than imported kerosene, part of the cost of the stove may be able to be placed in the fuel. A fraction of a cent of cost of the stove placed in the fuel allows the cost of the stove to be reduced very substantially over 3 to 5 years, depending on the number of stoves sold. Through this approach it may be possible to reduce the cost of a stove for a lower income market to as little as the current cost of a kerosene “China” or Panda stove. This, combined with micro credit financing, can place the stove within reach of many more consumers, including lower income consumers. Since the stove represents a long-term investment—10 years or more—it is actually cheaper to purchase and own over time than most stoves, which have to be replaced every few years or even several times a year. But the initial purchase price of the CleanCook stove is greater than the cheaper, less long-lasting stoves. Placing part of the cost of the stove in the fuel, or providing micro finance, overcomes this potential barrier to owning the stove.

The pilot study will also provide the opportunity for discussing with the Ethiopian government and other governments the appropriateness of creating government incentives and mandates for the use of the stove under special circumstances, for example in refugee resettlement areas where area biomass resources must be protected and where safe and clean cooking in cramped living quarters is a compelling need. While the dissemination of this stove and fuel by commercially sustainable means is obviously the most desirable approach to take, yet, there may—and we believe will—be circumstances where the CleanCook stove is of value as a tool of emergency relief and should be provided to the user who simply can't afford to acquire it on his or her own.

How Much Will Alcohol Fuels Cost?

This project seeks to make indigenously produced ethanol (in the shorter term) and an ethanol/methanol blend (in the longer term) available to Ethiopians for use as a household fuel for cooking. The economics of ethanol and methanol production are such that both alcohols could and should be available for purchase cheaper than kerosene not just initially but on a sustainable basis. Kerosene is subsidized not by reducing the price at which it was purchased abroad but through tax holidays. No federal excise tax, sales tax and municipality tax are charged on kerosene. Despite this favorable treatment of kerosene vis-à-vis other imported fuels and commodities, ethanol and methanol can be competitive. A decision by the government to grant the same tax holidays to alcohol fuels as to kerosene will obviously increase alcohol's competitiveness.

The cost to produce ethanol fuel, exclusive of capital and raw material costs, is as low as US 7¢ per gallon. The equivalent cost for methanol is about the same. The current retail price of kerosene is US 23 ½ ¢ *per liter*. These benchmarks suggest that fuel ethanol could without difficulty be priced well below kerosene. The cheapness of the fuel gives the consumer the opportunity to afford a better stove, provided that he or she can be given access to inexpensive and convenient financing if needed to make the initial purchase. The better stove, in this instance, also provides access to a superior fuel.

Table 3: Properties of Basic Fuels (following page)

Table 3: Properties of Basic Fuels

Property	Value					
	Methanol CH3OH	**Ethanol C2H5OH**	**Propane C3H8** (Butane is C4H10)	**Gasoline C4-C12** (up to C???)	**Kerosene C9-C16** (down to C5)	**Diesel C12-C23** (down to C5)
Molecular Weight	32	46	44	~114	~170 average	
Specific Gravity	0.789 (25C)	0.788 (25C)	0.585 (-40C)	0.739(15.5C)	0.820(15.5C)	
Vapor Density Rel. to Air	1.10	1.59	1.56	3.0 to 4.0	4.5 to 5.9	4.5
Liquid Density (g cm^{-3} at 25ºC)	0.79	0.79	0.50	0.74	0.79 to 0.84	
Boiling Point (ºC)	65C (149F)	78C (172.4F)	-42.5	27 to 245	200 to 250 spec 148 to 325	150 to 355
Melting Point (ºC)	-98	-144				
Vapor Pressure@38ºC (psia)	4.6	2.5	208	8-10	~1 and up	~1and up
Heat of Evaporation (Btu/lb)	472	410		135		
Heating Value (kBTU gal^{-1}) Lower Upper	58 65	74 85	81 88	111 122	121 130	130
Tank Design Pressure (psig)	15	15	325	15	5	
Viscosity (cp)	0.54	1.20		0.56	2.37	1.7 to 3.4
Flash Point (ºC)	11	14	-104	- 45	~38 ASTM spec 21 to 82	38 to 55 ASTM 21 to 82
Flammability/Explosion Limits (%) Lower (LFL) (%) Upper (UFL)	6.7 36	3.3 19	2.1 9.6	1.3 7.6	0.6 to 1.7 5	0.5 7.5
Auto ignition Temp. (ºC)	460	363	450	250 to 460	210	254 to 446
Solubility in H_2O (%)	Miscible(100%)	Miscible(100%)		Negl. (~. 001)	Negl. (~. 001)	Negl. (~. 001)
Azeotrope with H_2O	None	95% EtOH Hygroscopic	Immiscible	Immiscible	Immiscible	Immiscible
Peak Flame Temperature ºC	1870	1920	1925	2030	2038	2054
Minimum Ignition Energy In Air (mJ)	0.14		0.26	0.23	0.23	0.23
TLV for Exposure (ppm)	200	1000	1000	300 1ppm only for benzene	20 to 100 .01 to 25 for particulate matter in air	10 to 100 .01 to 25 for particulate matter in air

Table 4: Properties of basic fuels that influence safety of manufacture, transport, storage, and use. Values for gasoline, kerosene and diesel reflect a typical base-fuel value and the potential for variability. (Data compiled from standard chemical engineering reference works and representative industry Material Safety Data Sheets.)